Feedforward Equalization with Diverse Optical Filtering

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Abstract—**We explore CD compensation with feedforward equalizer (FFE) after diverse optical filtering (DOF), through which part of the phase information in the optical signal can be retrieved by the following direct detection. Simulation results show that the CD compensation capability of FFE can be significantly enhanced. In addition, unlike conventional direct-detection FFE whose CD compensation performance saturates, DOF-FFE can compensate larger amount of CD with more taps.**

Keywords- Chromatic dispersion; diverse optical filtering; electronic equalization; optical fiber communication

I. INTRODUCTION

In optical fiber transmission systems and networks, chromatic dispersion (CD) is one of the major fiber transmission impairments and traditionally it has been compensated in optical domain. In the past ten years much research effort has been focused on CD compensation in electrical domain, which is compact, flexible, and cost-effective [1]-[6]. For long-haul optical fiber transmission systems and networks the accumulated CD can be effectively compensated with feedforward equalizer (FFE) combined with coherent detection [1]. However, for short- and medium-range optical fiber transmission systems and networks direct detection is preferred because it is relatively cost-effective. Due to the squared-law characteristics of the photodiode the overall direct-detection optical fiber transmission system is essentially nonlinear, so that FFE and decision-feedback equalizer (DFE) are much less effective [2]. Although maximum-likelihood sequence estimation (MLSE) does have much higher CD compensation capability with direct detection, it needs sufficient number of states which grows exponentially with the CD value [3].

One way of compromising between CD compensation performance and its cost is full-field reconstruction [4]. In the scheme the optical signal first passes through a delay interferometer (DI), and then both the signals from the constructive and destructive ports of the DI are directly detected. The complex envelope of the optical signal can be partly recovered, and the CD accumulated in the optical signal can be better compensated.

We have also proposed diverse optical filtering (DOF) to enhance the performance of electronic equalizers, without employing coherent detection [5][6]. In this presentation, we will investigate the CD compensation capability of FFE with DOF, which is realized by super-Gaussian filters or differential-group-delay (DGD) filters.

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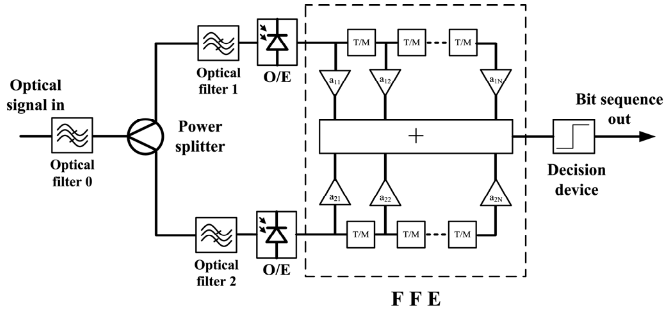

Fig. 1. Configuration of DOF-FFE.

II. CONFIGURATION OF DOF-FFE

The general configuration of DOF-FFE is shown in Fig. 1. The optical signal, after passing through an optical filter for removing out-of-band amplified spontaneous emission (ASE) noise, is split into two branches and filtered by two optical filters with different filter characteristics. After detected by two photodiodes for optical-to-electrical (O/E) conversion, the two electrical signals are jointly equalized by an FFE and the output is fed into a decision device to retrieve the transmitted bit sequence.

Although the effect of CD on the complex envelope of the optical signal is linear, in direct detection only the amplitude of the complex envelope can be detected, making the overall optical fiber transmission system essentially nonlinear. FFE, being a linear filter, thus has limited performance in CD compensation. After DOF, the amplitude of the complex envelope of the optical signal is related to the phase of the complex envelope of the optical signal *before* optical filtering. Thus through DOF followed by joint equalization, the performance of FFE for CD compensation can be significantly enhanced.

III. SIMULATION RESULTS AND DISCUSSIONS

We simulate the CD compensation performance of DOF-FFE in a 42.7 Gbit/s non-return-to-zero on-off keying (NRZ-OOK) system. For DOF we consider two types of optical filters: second-order super-Gaussian filter that is widely used in

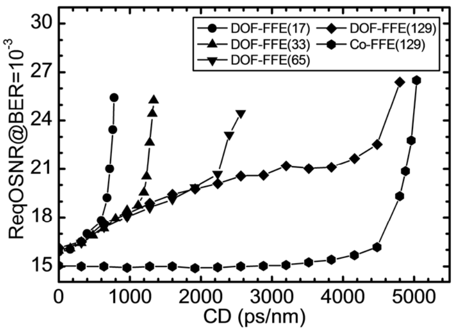

Fig. 2. Required OSNR as functions of CD for super-Gaussian DOF-FFEs with different number of taps.

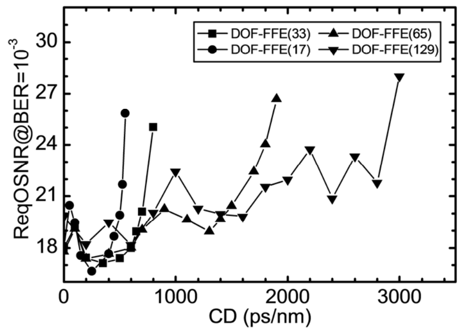

Fig. 3. Required OSNR as functions of CD for DGD DOF-FFEs with different number of taps.

optical fiber transmission systems, as well as DGD filter that has parameters that are easy to adjust, e.g. by temperature tuning.

A. *Super-Gaussian filters*

For super-Gaussian DOF-FFE we consider the cases when the number of taps for each of the two branches is 17, 33, 65, and 129, respectively. The *bandwidth* and the *detuning* of the two diverse optical filters are separately optimized for the cases with different number of taps. In the optimization we found that in order to compensate larger amount of CD with increased number of taps, a narrower bandwidth was required. More discussion on the optimization of the filter characteristics will be given in the presentation.

The required OSNR as functions of CD for super-Gaussian DOF-FFEs with 17, 33, 65, and 129 taps for each branch, as well as that for coherent FFE with 129 taps, are shown in Fig. 2. When the CD is within 4,300 ps/nm the required OSNR for coherent FFE (Co-FFE(129)) remains roughly the same, and the required OSNR rises abruptly when the CD exceeds 4,500 ps/nm. For super-Gaussian DOF-FFEs before rising abruptly the required OSNR increases slowly and monotonically. When the number of taps for each branch is 17 (DOF-FFE(17)), the OSNR penalty is less than 1.9 dB at 600 ps/nm, after which the required OSNR begins to rise abruptly. When the number of taps increases to 33, 65, and 129, the CD values corresponding to the turning points of the required OSNR curves are 1,120 ps/nm, 2,200 ps/nm, and 4,200 ps/nm, respectively. Since DOF-FFE uses real multiplication and coherent FFE uses complex multiplication, the DOF-FFE only requires half real multiplications compared with the coherent FFE when the number of taps for each branch of the DOF-FFE equals the number of taps for the coherent FFE.

B. *DGD filters*

Fig. 3 shows the required OSNR as functions of CD for DGD DOF-FFEs with 17, 33, 65, and 129 taps for each branch. Unlike that with super-Gaussian DOF-FFEs, the required OSNR with DGD DOF-FFEs is small only at particular CD ranges and does not monotonically increase with respect to CD. For instance, DGD DOF-FFE which has 33 taps for each of the two branches (DOF-FFE(33)) performs the best at 350-ps/nm CD, but not at zero CD. Therefore, DGD DOF-FFE is more suitable for compensating CD for a fixed transmission link. When the number of taps for each branch is 17 (DOF-FFE(17)), at 350-ps/nm CD the required OSNR is 16.9 dB, which is only 0.3 dB higher than that for the super-Gaussian DOF-FFE with the same number of taps. The required OSNR begins to rise abruptly when the CD exceeds 500 ps/nm. As the number of taps for each branch increases to 33, 65, and 129, the turning points of the required OSNR curves increase to 700 ps/nm, 1,300 ps/nm, and 2,900 ps/nm, respectively.

IV. CONCLUSION

We have explored CD compensation for NRZ-OOK signals with DOF-FFEs. Two types of optical filters, super-Gaussian filter and DGD filter are considered. Simulation results show that with DOF the CD compensation performance of FFE can be significantly enhanced. Super-Gaussian DOF-FFE can be utilized in transmission systems with dynamic links, whereas DGD DOF-FFE is more suitable for fixed transmission link. With some OSNR penalty both the two types of DOF-FFEs can compensate larger amount of CD with increased number of taps. DOF-FFEs are competitive candidates for compensating CD in short- and medium-range optical fiber transmission systems and networks in which cost is an import factor to be taken into account when the systems are designed.

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